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Research and Technology Breakthroughs in Nuclear Power for Shaping a Sustainable Low-Carbon Energy Future

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Abstract

Research for nuclear energy features high costs and long lead times as it makes use of materials testing reactors and hot laboratories, and is submitted to stringent safety regulations. These specific requirements have much contributed to make nuclear reactors evolving in an evolutionary manner. This is evidenced by currently commercialized generation III light water reactors (LWRs) that mainly rely on today's operating reactors' technologies engineered in such a way as to optimizing their safety and economic performance. Globalization of research and development together with enhanced capabilities for science driven research allowed by more and more refined characterization and numerical simulation techniques create conditions today for achieving real breakthroughs in technologies and processes, as well as in design and safety studies of nuclear systems.

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The development of multi-scale modelling of materials science that enables assessing the margin against pressure vessel embrittlement with neutron damage constitutes a real breakthrough for providing a scientific basis for confidently extending the lifetime of lightwater reactors (LWRs) (Figure 1)

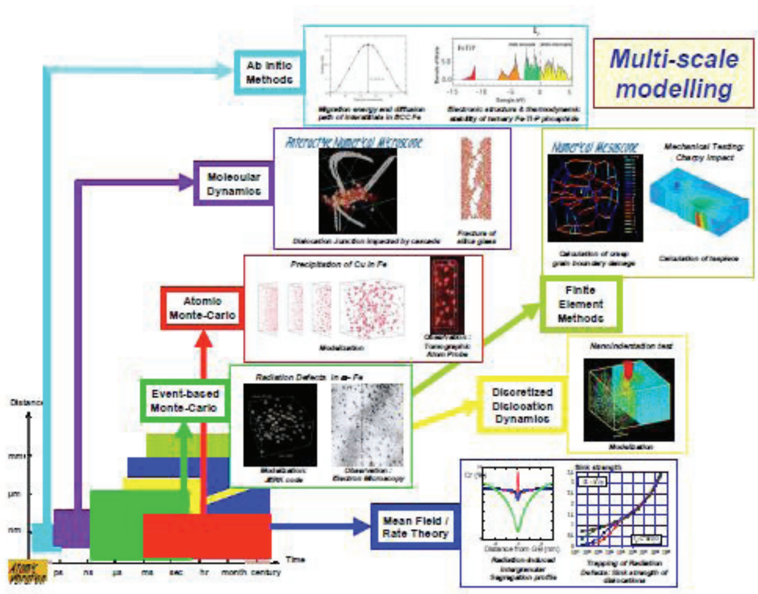

Fig.1. Materials science multi-scale modelling

The capability of materials science to make advances in structural materials and fuels more predictable also benefits to improving performances of future reactors and nuclear fuels. Breakthroughs in numerical simulation also enable today safety demonstrations that cannot be made experimentally such as the safe management of severe accidents or the long term behaviour of radioactive waste packages (Figure 2).

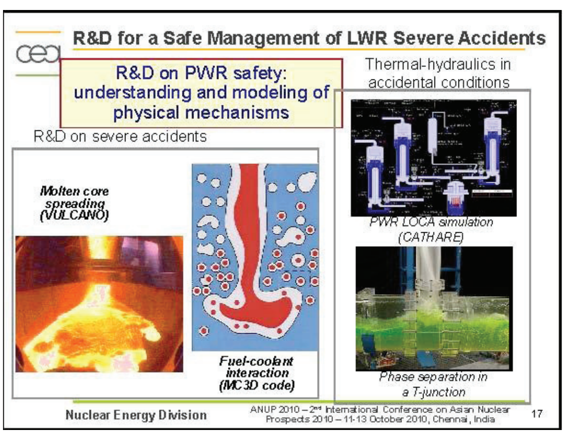

Fig.2.severe accidents research, physical modeling and numerical simulation

Multi-scale modelling is also available today for comprehensive studies of transient operating analyses of complete nuclear systems with two directions of development: refined modelling of local elementary phenomena, as enabled by the progress of analytical research, and the assets of high performance computing methods (Figure 3). Breakthroughs are also sought in reactor designs to make LWRs best fit evolving needs over the 21st century such as small power reactors with simplified designs to offset the scaling effect on investment cost or high conversion ratio MOX fuelled reactors to somewhat improve the utilization of Uranium.

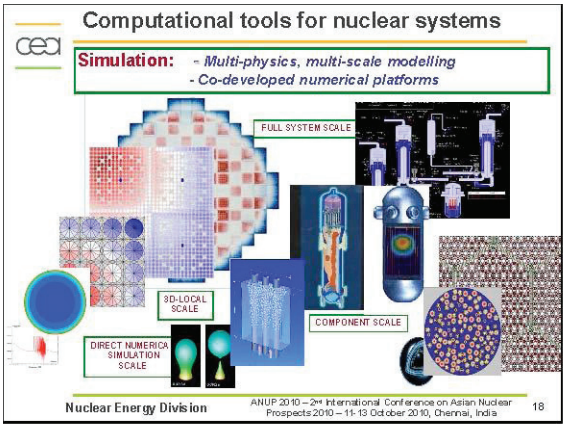

Fig.3. Multiscale modelling of nuclear systems

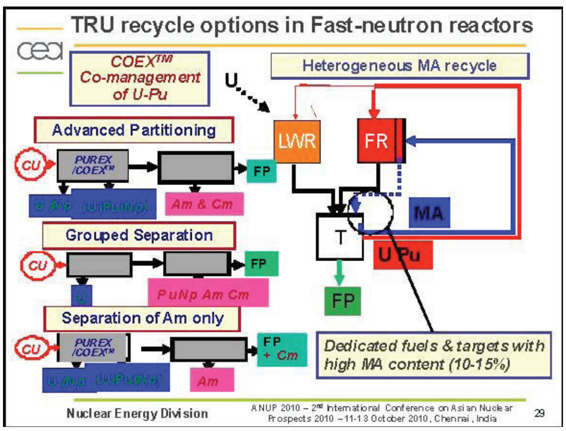

Fig.4.Candidate recycling modes in fast neutron reactors

Goals of efficient utilization of Uranium (>80%) and minimization of long-lived radioactive waste prompted the international recognition of fast neutron reactors and closed fuel cycles as key nuclear systems to achieve these goals. Similarly, goals of extended applications of nuclear power beyond the sole production of electricity prompted a revival of interest in high temperature reactors for producing hydrogen, synthetic transportation fuels and process heat for the industry as prime applications. Such generation IV nuclear systems by nature call for breakthroughs to extend LWRs capabilities. As for LWRs, materials science enables more predictive research in advanced structural materials and fuels needed to resist fast neutron damages and high temperature. Current resumption in France of research on sodium cooled fast neutron reactors (SFRs) definitely aims at significant progress in safety and economic competitiveness compared to earlier reactors of this type in order to progress towards a new generation of commercially viable sodium cooled fast reactor [1]. Varied breakthroughs in core design and fuel technology are currently investigated to exclude by design most accidents likely to initiate severe accidents and hence practically exclude accidental large energy release. Progress in safety also drives a specific interest in gas power conversion systems that avoid the use of water and subsequent risks of sodium-water interactions. Progress in safety and operability also call for innovations in reactor instrumentation and controls, as well as in techniques for in service inspection and repair. Closing the nuclear fuel cycle of fast neutron reactors represents in itself a breakthrough as it enables recycling all nuclear materials generated by LWRs including Plutonium, reprocessed Uranium and depleted Uranium. Minor actinide recycling is an active field of research [2] aiming at assessing the technical feasibility and the additional cost associated with minimizing the long term decay heat and radiotoxic inventory of high level radioactive waste, as well as with potential benefits on non-proliferation (Figure 4). The identification in France of mixed carbide fuel as longer term option for improving safety and breeding performance, as well as preference for metallic fuel in some other countries would feature another type of breakthrough compared to MOX fuel that has been the most widely used fuel so far in fast neutron reactors.

Along with advancing sodium cooled fast reactor design and technologies, research and development on alternative fast reactor concepts, such as gas or lead-alloy cooled systems is strategic to overcome technical difficulties and/or political opposition specific to sodium. Such alternative fast reactor designs definitely call for technology breakthroughs in the field of structural materials, nuclear fuels, and technologies for cooling systems and power conversion.

In spite of the strong experimental program in the HTTR in Japan, and significant projects such as the HTR-PM in China, the NGNP in the United States and the PBMR in the Republic of South Africa, high temperature reactors (HTRs) seem to currently yield priority to fast neutron reactors projects that are envisioned as avenues towards sustainable nuclear power. This in part stems from current low fossil fuel prices and low carbon taxes that cause a lack of willingness of potential end-user industries to commit themselves to nuclear power. However, as for fast neutron reactors, there is a clear recognition that current trends should better value HTR cogeneration products in the medium term and thus create a more favourable context for the deployment of this type of reactor. Breakthroughs required for next generation HTRs include a small unit power (< 300 MWe) to achieve passive safety features, steel in place of pre-stressed concrete for the pressure boundary of the primary system, and gas turbines (in place of steam turbines) for advanced power conversion systems (possibly in direct cycle). Such novel features definitely calls for technology advances in the fields of structural materials, nuclear fuels, high temperature helium systems and non conventional energy conversion systems (gas turbine, advanced electrolysis, adapted industrial processes and associated heat exchangers…).

In conclusion, research and technology breakthroughs in nuclear power are needed for shaping a sustainable low carbon future. This includes new designs for more robust and less uranium consuming light water reactors, as well as fast neutron reactors and high temperature reactors for more sustainably meeting varied and fast growing primary energy needs anticipated over the 21st century. Such future nuclear energy systems definitely call for modelling and simulation-assisted advanced designs and technology breakthroughs, as well as for cross-fertilization with advanced technologies developed for non nuclear applications or for fusion devices such as advanced materials, instrumentation, chemical processes and energy conversion systems.

International cooperation is key for sharing costs of research and development of the required novel technologies and cost of first experimental reactors needed to demonstrate enabling technologies. At the same time technology breakthroughs are developed, pre-normative research is required to support codification work and harmonized regulations that will ultimately apply to safety and security features of resulting innovative reactor types and fuel cycles.

References

[1] French Research and Development Program and Design Activities for SFR Prototype ASTRID, François Gauché (CEA), ANUP 2010

[2] Future Nuclear Fuel Cycle: main Guidelines for the French Program, Bernard Boullis (CEA), ANUP 2010